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ORIGINAL ARTICLES.

The Millstone Grit of Gower.

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Introduction.

THE Millstone Grit described in this paper forms a belt of country about a mile wide, stretching from west-north-west to east-south-east across the north of the Gower Peninsula. Reference is also made to small areas of Millstone Grit preserved in synclines at Oxwich and Porteynon on the south coast of Gower. These areas form the most important outcrops of this formation on the south of the South Wales Coalfield. Further east the Millstone Grit is thinner and it is not exposed for some miles to the east of Swansea Bay, as it is concealed by Mesozoic rocks.

The Officers of the Geological Survey divided the Millstone Grit of the north crop of the South Wales Coalfield into three groups, namely :—

Farewell Rock.
Shale group.
Basal Grit.

These sub-divisions can best be recognized along the north crop of the coalfield, but as they are traced westwards from the Black Mountains to Kidwelly, the sandy beds become less prominent and pass into shales.

In Gower the shaly facies predominates, with only a few subordinate sandy and quartzitic beds, which are often lenticular in form and more abundant near the top of the series. It is quite impossible to identify the lithological divisions of the north crop. The thickness has been estimated at 1,500 feet (*Swansea Memoir*, 1907, p. 29).

The Millstone Grit in its main outcrop in Gower gives rise to an upland tract of rather barren country. Over much of the area it is covered by Boulder Clay and there are few exposures, except in some stream beds. Temporary road sections have afforded much of the information on which the following notes are based. The

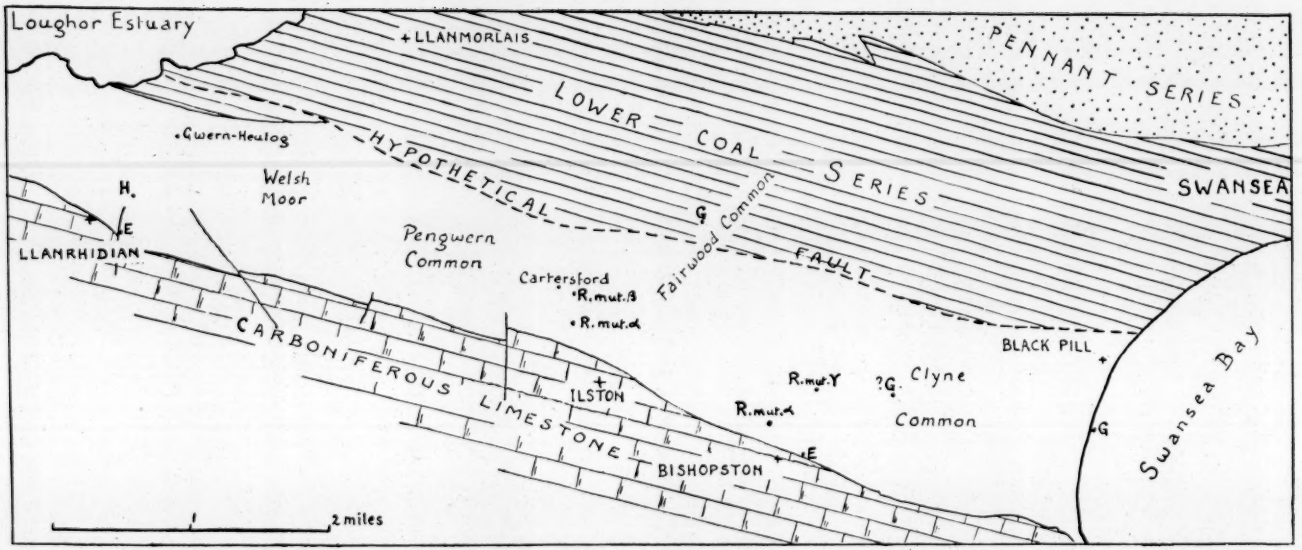

FIG. 1.—Diagram-map showing the main outcrop of Millstone Grit in Gower. The horizons represented by certain Goniatites are indicated. Adapted from the one-inch map of the Geological Survey, Sheet 247.

exposures are so isolated that it is quite impossible to determine in detail the structure of the area; generally the dips are steep, mostly 40 to 50 degrees, but it is evident from the number of southerly dips which have been observed that sharp folds, trending approximately east to west, occur. By analogy with the area to the north occupied by the Lower Coal Series, it is probable that these folds are frequently accompanied by thrust faulting (*Swansea Memoir*, 1907, p. 52; Dix and Trueman 1924, p. 355).

Correlation.

There has been great difficulty in the past in correlating the Millstone Grit of South Wales with that of other areas in Great Britain owing to the great variation in thickness and the character of the deposits. Although the Millstone Grit has been referred to the Upper Carboniferous it has been uncertain whether it corresponds to any part of the Millstone Grit of the north of England. It has been stated on the evidence of the plants, that at least a part of the Millstone Grit of Pembrokeshire is of Middle Coal Measure (or Yorkian) age (Goode, 1913, p. 272). Similar conclusions were drawn by Dr. R. Crookall concerning the Millstone Grit of Somerset (1925, p. 403). On the other hand, investigations on the non-marine lamellibranchs of the Upper Carboniferous appear to indicate that the lowest part of the Lower Coal Series of South Wales is equivalent to some part of the Lower Coal Measures of the north of England (Davies and Trueman, 1927, p. 253), while Messrs. D. G. Evans and R. O. Jones have recently shown that the goniatites of the Millstone Grit of a portion of the north crop of the South Wales Coalfield indicate the presence there of the zones H, R, and G of Mr. W. S. Bisat's sequence (1923, 1924, 1927).[1] Similar conclusions have been reached in other parts of the north crop by other workers (O. T. Jones, 1925, p. 558; Kitchin, 1926; *Abergavenny Memoir*, p. 43; George, 1927, p. 81).

The approximate equivalence of the Millstone Grit of South Wales and the north of England may thus be considered to have been established. This view is supported by recent work on the flora of the lower part of the Upper Carboniferous in South Wales which reveals a succession of floras similar to those of the north of England and Scotland and of the Continent.[2] (Dix, Pringle and Trueman, 1930, p. 324.)

The Relation of the Millstone Grit to the Lower Carboniferous.

Mr. E. E. L. Dixon showed (*Newport Memoir*, p. 20) that at certain places along the eastern crop of the South Wales Coalfield there

[1] Recently the writer discovered specimens of *Eumorphoceras* sp. in shales associated with Radiolarian Cherts at Careg-y-Dwfan, Carmarthenshire (*Ammanford Memoir*, p. 76).

[2] Since this paper was written, Dr. R. Crookall (1931) has published a paper drawing a similar conclusion.

is ample evidence of an unconformity between the Millstone Grit and the Carboniferous Limestone. Subsequent work on this and other areas has established the wide extent of this unconformity (*Haverfordwest Memoir*, p. 151 ; Dixey and Sibly, 1917, p. 123; Dixon, 1921, p. 157 ; Dixon and Pringle, 1927, p. 124 ; George, 1927, p. 51 ; Evans and Jones, 1929, p. 164, and Robertson and George, 1929, p. 4).

In Gower, however, little or no evidence of such an unconformity has been available. Between the black shales which are of undoubted Millstone Grit age and the Upper Limestone Shales (locally represented by Rottenstones) which are admittedly of Avonian age, there occur shales with Radiolarian Cherts. These latter have been grouped by some writers with the overlying beds, and by others with the Avonian (*Swansea Memoir*, 1907, p. 28). Hind and Dixon correlated the Radiolarian Cherts with the Pendleside Series of the north of England. The evidence of the goniatites which occur in association with the Radiolarian Cherts indicates that they should be grouped with the Upper Carboniferous.

The Relation of the Millstone Grit to the Coal Measures.

The junction of the Millstone Grit with the Lower Coal Series of Gower is shown on the Geological Survey Map (1 inch sheet 247) as a " Hypothetical Fault ". The separation of the Millstone Grit from the Lower Coal Series is a matter of great difficulty, owing to the lithological similarity of both series near their junction and to the highly disturbed character of the strata. It appears, however, that in some places Millstone Grit occurs to the north of the mapped " fault " and possibly Coal Measures to the south of it ; it would thus seem probable that the strata are sharply folded along the presumed boundary.

The present work records a number of observations made in the scanty natural exposures, cuttings and stream sections and also a few temporary exposures during the construction of roads. An attempt is made to determine the goniatite sequence and to correlate the Millstone Grit of Gower with that of the north crop of the South Wales Coalfield and with that of the north of England.

Local Details

1. *The Bishopston Area including Barland Common.* (Fig. 2.)

It will be convenient to deal first with the Bishopston Area, because the lower part of the Millstone Grit is well exposed in the well-known Bishopston road cutting and because a section at the base of the sequence was exposed in the making of a new road.

At Bishopston, the Main Limestone is overlaid by Rottenstone Beds of D_{2-3} age which are succeeded by Radiolarian Cherts, interbedded with coarse brownish shales containing poorly preserved specimens of *Eumorphoceras* ? cf. *pseudobilingue*, and *Posidoniella* sp.

(locality 1, Fig. 2). The Radiolarian Cherts are overlain by a series of black cherts and shales, containing at their base *Cordaites* sp., *Calamites* sp., *Posidonomya* aff. *membranacea*, and *Posidoniella* sp. These fossils were found in beds which were exposed in the making of the new road on the east side of the valley, north of Bishopston Church (see Fig. 2, locality 2).

A series of good exposures of higher beds is seen in a stream section on Barland Common. At locality 3, black shales and cherts containing abundant *Leiopteria* cf. *longirostris*, and *Eumorphoceras* cf. *pseudobilingue* are dipping steeply northwards. Near this

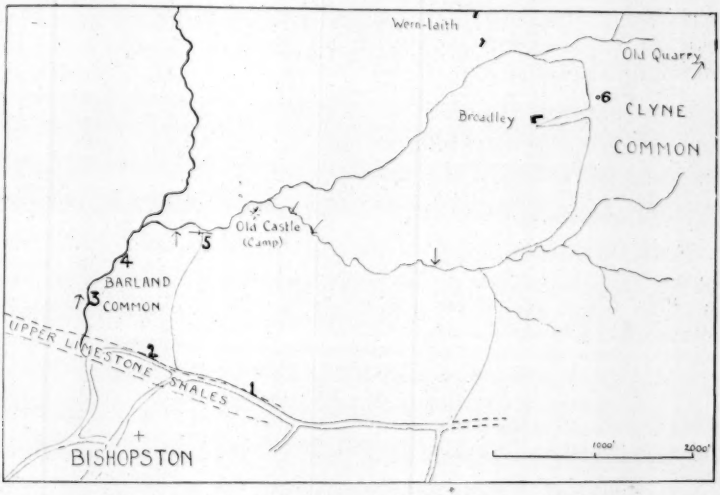

FIG. 2.—Sketch-map of the Bishopston Area showing the chief localities where fossils have been found. Adapted from the six-inch map of the Geological Survey (Glam. XXIII S.W.).

horizon are occasional calcareous nodules, ranging up to a foot in diameter and resembling the " bullions " of the north of England. These are succeeded by about 100 feet of black shales with thin chert bands, overlain by sandy shales containing thin grits and quartzites. In the shales at locality 4 the following fossils were found :—

Posidoniella sp. (cf. *rugata*).
Pterinopecten aff. *speciosus*.
Orbiculoidea sp.
Reticuloceras reticulatum mut. *a* (*R. bilingue*).
R. cf. *inconstans*.

These fossils clearly indicate the lower part of the zone R.

About half a mile north of Bishopston Church (locality 5) Dr. J. Pringle some years ago collected *Posidoniella* aff. *rugata*, *Lingula mytiloides* and *Posidoniella* sp., and he also collected a number

of fossils in dark grey shales from the same stream section, but 70 yards above the previous locality and on the east bank. The following species have been determined :—

Orthoceras sp.
Reticuloceras sp.
Homoceratoides divaricatum.
Cf. *Posidoniella* sp.

These specimens are preserved in the collections of the Museum of Practical Geology.

On the left bank of the stream ¼ mile east of Old Mill, east of north of Bishopston Church (locality 5), dark micaceous shales, stained red, outcrop. In these shales numerous fossils were found, including the following :—

Reticuloceras reticulatum mut. γ (*R. superbilingue*).
Homoceratoides divaricatum.
? *Dimorphoceras* sp.
Pterinopecten sp.
Cordaites sp.

Fossils were collected from the right bank of the stream at this locality by the Officers of the Geological Survey (*Swansea Memoir*, p. 25). These specimens have been examined, and the following species have been identified :—

Reticuloceras reticulatum mut. γ (*R. superbilingue*).
Homoceratoides divaricatum.
Homoceras proteum.
? *Gastrioceras lineatum.*
Pterinopecten sp.
Posidoniella sp.

This horizon is clearly within Bisat's zone of R 2.

A few years ago a slant was opened to a seam about 1 ft. 10 in. in thickness on Clyne Common, about 150 yards north of east of Broadley (locality 6). On the tips of this old colliery and in the neighbouring stream are blue-grey, fine grained shales containing *Cordaites* sp., *Stigmaria ficoides*, and a large number of fresh-water shells. The following species have been identified :—

Carbonicola cf. *communis* Davies and Trueman.
C. cf. *recta* Trueman.
C. sp. nov.
Anthracomya bellula Bolton.

The occurrence of these fresh-water shells is of particular interest because they are known to occur at the same horizon in other areas in South Wales, and include species which are found in the higher part of the Millstone Grit and lowest Coal Measures in Yorkshire.

Above these shales are a thick series of shales with several

lenticular quartzite bands forming Clyne Common. A few exposures are seen in old quarries on the Common but no fossils have been collected.

2. *Area East of Bishopston* (*Shore Section at Blackpill*).

On the foreshore in Swansea Bay in the neighbourhood of Blackpill a series of grits and shales is exposed. A detailed examination of this section has been made. In general the beds dip steeply to the north at an angle varying from 30 to 80 degrees, but near the southern end of the outcrop an anticline is seen with an axis running approximately east–west. The rocks exposed consist chiefly of dark, sandy, micaceous shales with several tough olive sandstones (some ferruginous) of varying thickness. At several horizons thick sandy fireclays occur containing Stigmarian rootlets and sometimes succeeded by thin coal seams from $\frac{1}{4}$ in. to 1 foot in thickness. Black, fine grained shales occur rarely in the section, and traces of limestone nodules are seen near the middle of the exposure.

Fossils were found about 46 feet above the crest of the anticline. They were found in dark micaceous shales overlying a tough sandstone. The following fossils have been identified :—

Gastrioceras cumbriense.
Dimorphoceras sp.
Pterinopecten sp.
Lingula mytiloides.
Edmondia arcuata.
Sanguinolites sp.

Plant fragments including *Calamites* sp., *Neuropteris gigantea*, and *Alethopteris* sp. were found higher in the sequence.

The fossils indicate that some part of Bisat's zone G is represented on the foreshore at Swansea Bay. It is significant to note that in lithological characters these beds closely resemble certain bands within the Farewell Rock on the north crop of the coalfield.

North of the Mayals and east of Clyne Castle are a few sandstones similar to those on the foreshore, all of which can only be traced for a few yards and are sharply folded.

3. *Area near Courthouse Farm.*

The Radiolarian Cherts are exposed in an old road cutting near Courthouse Farm to the west of Bishopston, where they overlie fossiliferous Rottenstone Beds of D_{2-3} age similar to those at Bishopston. In the thin coarse shales interbedded with the cherts numerous poorly preserved specimens of *Posidoniella* aff. *membranacea* occur but no trace of goniatites was seen (locality 8, Fig. 3).

In the stream section near Courthouse Farm, massive beds of D_{2-3} age are seen dipping steeply to the north. These are succeeded

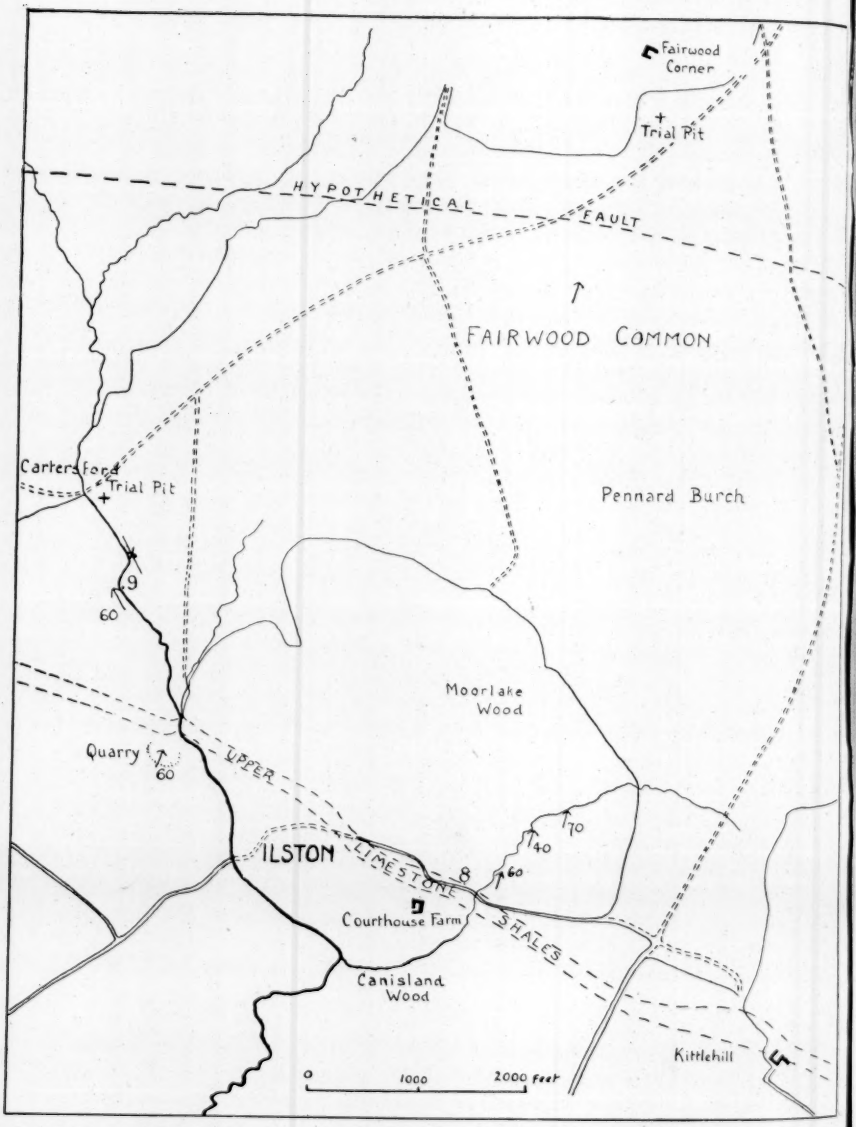

FIG. 3.—Sketch-map of the area around Ilston showing localities where fossils were found. Adapted from the six-inch map of the Geological Survey (Glam. XXIII S.W.).

by cherts followed by a series of black cherts and shales which in turn are overlain by dark, coarse shales interbedded with grit bands. Unfortunately, no fossils were found in these shales.

4. *Ilston Stream Section.*

Going westwards the next exposure of Millstone Grit is seen in a stream section near Ilston. The main limestone is well exposed in a large quarry near Ilston village where pseudobreccias of D_1 age are worked. The remarkable feature about this quarry is the occurrence of a thin coal seam from 1 to 1 ft. 3 ins. thick underlain by fireclay and immediately overlain by massive limestone. A number of small, coaly lenticules are also seen.

The D_{2-3} Rottenstones and the Radiolarian Cherts are not exposed near Ilston. In the Ilston stream on Fairwood Common, south of Cartersford Bridge, is exposed a thick series of black, sandy shales interbedded with thin quartzites, similar to that at Bishopston. These beds dip steeply to the north and are sometimes sharply folded. Fossils were found in black shales at the bend of the stream (locality 9, Fig. 3). The following species have been identified :—

Reticuloceras bilingue Salter (*Reticuloceras reticulatum* mut. α).
R. cf. *inconstans.*
Posidoniella aff. *rugata.*
Pterinopecten aff. *speciosus.*
Orbiculoidea sp.

The goniatites indicate the horizon of *R. reticulatum* mut. α Bisat, and Dr. J. W. Jackson identified the lamellibranchs with forms from that horizon in the north of England.

A few years ago a slant was made near Cartersford Bridge in the hope of finding a coal seam believed to exist in the neighbourhood. No seam was discovered but the shales on the tip yield a rich goniatite fauna. These were preserved in black, thinly bedded, well laminated shales and have been identified as *Reticuloceras reticulatum* mut. β similar to those found in Bisat's Zone of R 2. *Pterinopecten* aff. *speciosus* and *Posidoniella* aff. *rugata* were also found in these shales.

In the upper part of the stream, thick sandstones occur interbedded with sandy shales. These beds dip steeply northwards and are almost vertical along the line of the " hypothetical fault " (*Swansea Memoir*, p. 30). It is probable that these sandstones correspond to the sandy beds exposed in the upper part of the sequence at Swansea Bay, but, unfortunately, there is no palaeontological evidence to support this correlation.

5. *Old Tip, Fairwood Common.*

Several trial pits were made on Fairwood Common in the search for coal seams. On one of the rubbish tips (200 yards south of Fairwood Corner) a quantity of coarse, light grey quartzite was

found, together with black, well laminated shale containing the following fossils :—

Gastrioceras cumbriense.
Gastrioceras coronatum.
Posidoniella aff. *rugata.*
Pterinopecten sp.
Lingula mytiloides.
Loxonema sp.

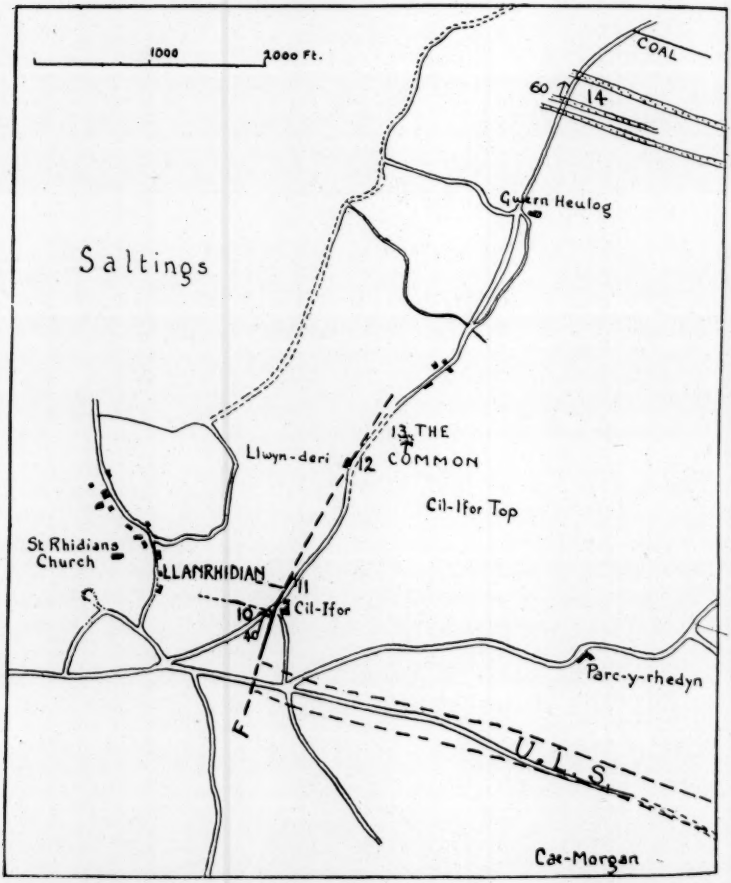

FIG. 4.—Sketch-map of the area around Llanrhidian showing localities where fossils were found. Adapted from the six-inch map of the Geological Survey (Glam. XXII S.W., XXII N.E., XX S.E.). [U.L.S., Upper Limestone Shales.]

In some blue-grey shale plant remains were found, including *Lepidodendron obovatum* Sternb., *Calamites* sp., *Cordaites* sp., and *Stigmaria ficoides* Sternb.

The fauna indicates a horizon in Bisat's Zone G, and according to Mr. R. O. Jones probably represents a horizon lower than the Farewell Rock horizon of the north crop of the coalfield (Evans and Jones, 1929, p. 172).

6. *Section near Pengwern Farm.*

In Pengwern farmyard and in the lane nearby, dark grey, rather sandy shales outcrop, dipping northwards at an angle about 40 degrees. These shales are unfossiliferous.

Near Llethrid black shales are seen succeeded by thin sandstones some of which are ferruginous in character, interbedded with shales. The sandstones are exposed at intervals for nearly two miles. The Millstone Grit gives rise in this neighbourhood to moorland tracts including Pengwern Common, Forest Common, and Welsh Moor.

7. *Llanrhidian Area, including Cil-Ifor.* (Fig. 4.)

At Llanrhidian a good section in the Millstone Grit was exposed in the making of the new road from Llanmorlais to Llanrhidian. The Main Limestone, consisting of fossiliferous pseudobreccias, probably of D_1 age, outcrops in a field and in the new road (locality 10, Fig. 4), and can be traced to the entrance of Cil-Ifor Farm. It dips northwards at an angle from 30 to 40 degrees. No trace of the Upper Limestone Shales was seen, although Mr. G. Gordon informed the writer that he came across some yellowish clays to the north of the Main Limestone in making a pit, now covered over.

In the rickyard adjoining the farm (*Swansea Memoir*, p. 18), about 30 feet of coarse, buff-coloured quartzite outcrops, dipping to the north at an angle of 35 degrees. When the new road was made this quartzite was exposed, but has since been concealed by a wall. It appears to be overlain conformably by about 20 feet of dark, coarse grained, flinty shales and cherts. Some of the cherts are striped and closely resemble the Radiolarian Cherts of the Bishopston area. The flinty shales weather in a peculiar manner and some bands are very fossiliferous. The following species have been identified :—

Anthracoceras glabrum.
Eumorphoceras bisulcatum.
Pterinopecten sp. nov.
Posidonomya cf. *corrugata.*
Posidonomya sp.
Pseudamusium sp. (cf. *pretenuis*).
Orthoceras sp.
Chonetes sp.
Crinoid-stems.
? Spines of *Productus longispinus.*
Archaeocalamites sp.

The fauna found at this horizon indicates that it is within Bisat's zone of E. Dr. J. W. Jackson informed the writer that both the lithology and the fossils found at this horizon are very similar to those found in the middle of zone E in the Edale Valley, north Derbyshire (Jackson, 1927, p. 27).

These shales are succeeded by a series of finely bedded shales. Only a fragment of *Cordaites* was found in these shales.

8. *Sections on the Common, Llanrhidian.*

On the Common a good section in Millstone Grit shales can be seen in a road-cutting. The structure, however, is complicated by folding and faulting, and in places it is difficult to make out the sequence. Fossils were found at three horizons. In brown, unevenly bedded shales opposite the gate of Llwynderi House several specimens of goniatites were found. The majority of the forms belong to *Homoceras diadema* (coarsely striated forms); other fragments are *H.* cf. *proteum.*

About 15 to 20 feet above this horizon, a thin band of soft, and much weathered, light brown shales is found, containing numerous impressions of goniatites, identified as *Homoceratoides* sp., *Homoceras diadema*, *H.* cf. *diadema* (finely striated form), and *H. eostriolatum.*

Sandy beds containing many large ironstone nodules are seen only a few feet higher in the sequence opposite a house about 35 yards north of Llwynderi. At this horizon some goniatites were found (including a few large forms), which have been referred to *Homoceras diadema* (finely striated form), *H.* cf. *diadema* and *H.* cf. *proteum.*

The above faunas clearly indicate the presence of Bisat's zone H of the Mid-Pennine area and correspond to the middle portion of the Upper Sabden Shales, and also to the middle portion of the Edale Shales of Derbyshire.

These shales are succeeded by blue, flinty, well laminated shales which are unfossiliferous except for fragments of *Cordaites.* In the quarry on the Common similar blue shales are seen in the centre of a syncline. Underneath the shales are thick sandstones in which Mr. Sargent has obtained beautiful crystals of wavellite; these are underlain by a series of micaceous sandy shales. At several places on the flanks of Cil-Ifor Tops there are exposures of blue, thinly bedded shales. Near Parc-y-Rhedyn Farm some black shales containing *Posidonomya* sp. and *Leiopteria* sp. are exposed in a roadside. These shales are similar to those found near the base of the Millstone Grit at Bishopston.

A section in Millstone Grit shales was exposed in the making of the new road on the north of the Common, about 400 yards north-east of Llwynderi, where blue unfossiliferous shales were seen dipping northwards at an angle of 40 degrees.

For about one quarter of a mile northwards the Millstone Grit is concealed by a thick covering of boulder clay. It is interesting

to note that some time ago a few trial pits were opened in the Marshlands Wood in the hope of finding a coal seam, but the shales have been destroyed by weathering.

About 300 yards to the north of Gwern-Heulog Farm[1] thick sandstones and sandy shales containing ironstone nodules, dipping steeply northwards, outcrop in the new road. Similar sandstones can be seen for some distance to the east passing under Llan Elen. These sandstones are probably the same as those exposed about Middle Hills and East Hills. Still farther northwards (about 100 yards) along the new road is another section with a thin coal seam underlain and overlain by sandstone.

Unfortunately, no fossils have been found in the latter exposures and neither the zones of R or G have been proved at Llanrhidian. The character of the beds in the road cutting north of Gwern-Heulog resembles that of the highest beds on the foreshore at Blackpill and they are probably near the Farewell Rock horizon of the north crop of the coalfield.

9. *Porteynon.*

At Porteynon some red and purple shales used to be dug and ground in the manufacture of paint. The old paint mine is situated 200 yards north of the church. At present very little can be seen in this old mine, but the Officers of the Geological Survey noted shales dipping southwards at 70 degrees and overlain by nearly horizontal Triassic conglomerate. In the collections of the Geological Survey there are specimens from this locality, collected by Dixon and Vaughan, which have been identified as *Eumorphoceras bisulcatum* and *Posidoniella* aff. *rugata* (previously identified as *P. becheri*). The specimens are preserved in striped cherts and, except for their red colour, could not be distinguished from those at the base of the Millstone Grit at Llanrhidian.

Nearby, at Overton, abundant cherts are found in the drift (*West Gower Memoir*, p. 18).

10. *Oxwich.*

Black shale and chert is also seen in the Oxwich syncline ; shale has been examined in a road near Penrice Mill. Unfortunately, previous exposures are overgrown and no fossils have been found to indicate the age of these beds.

General Sequence of Goniatite Zones.

It appears clear from a study of the goniatites found in the Millstone Grit of Gower that the zones from E to G of Bisat's zonal succession are represented. The study of the lamellibranchs, too, affords some evidence in support of this conclusion.

No evidence of any zone lower than the upper part of E has been

[1] This is spelt "Wern-halog" on the one-inch map, but the usual local spelling is used here.

found, and it appears likely that the zone of P and the lower part of zone E are unrepresented.

The lowest beds referable to the Upper Carboniferous are the Radiolarian Cherts, in which goniatites of zone E occur. These beds appear to rest conformably on the Upper Limestone Shales at Bishopston, but the absence of representatives of lower zones at this locality may possibly be explained by an unconformity of smaller extent than that which has been proved in many parts of South Wales. On the other hand, the zone P of the Mid-Pennine area may possibly be represented by some portion of the Upper Limestone Shales at Bishopston.

Zone upper E is definitely represented at Llanrhidian and Porteynon, and is very similar in character to the comparable horizon in the Edale Shales of Derbyshire.

Zone H is seen in the Llanrhidian area in the new road-cutting on the Common, but is not well represented elsewhere, and can only be thinly represented at Bishopston.

In stream sections at Bishopston and at Ilston the horizon of *R. reticulatum* mut. α has been identified, while at Ilston the horizon of *R. reticulatum* mut. β and at Bishopston, that of *R. reticulatum* mut. γ are present.

Zone G is represented on the foreshore at Blackpill and on Fairwood Common.

There is no apparent break between the Millstone Grit and the Coal Measures.

The writer wishes to thank Mr. R. O. Jones, M.Sc., for naming the goniatites mentioned in this paper and also for many helpful discussions on the Millstone Grit succession. She is also indebted to Dr. J. W. Jackson for naming certain lamellibranchs. Thanks must also be expressed to the Officers of the Museum of Practical Geology and especially to Dr. F. L. Kitchin and Mr. S. W. Hester for access to the Millstone Grit fossils in their collection.

Dr. T. N. George and Mr. W. D. Ware have given assistance in the field. The writer is again particularly grateful to Professor A. E. Trueman for his invaluable aid and criticism in the course of this work.

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A Sandstone with Fluorspar Cement and other Sandstones from West Cumberland.

By H. P. LEWIS, M.A., F.G.S.

SOME time ago Mr. Charles Edmonds provided me with a number of sandstones of Carboniferous age from West Cumberland to compare with the sandstones of the Peel Series in the Isle of Man. These specimens proved to have an interest peculiar to themselves which it is the purpose of this note to describe.

The petrographic characters of the sandstones between the First and Second Limestones have been studied more particularly and receive most attention; the other sandstones are considered chiefly from the point of view of their heavy mineral concentrates. The localities from which the specimens were collected are indicated in Fig. 1, and the vertical sections (Fig. 2) illustrate the sequence

between the First and Second Limestones at the Langhorn and Overend quarries.[1]

Petrographical Details.

The Sandstones between the First and Second Limestones.

Upper Sandstone, Langhorn Quarry.—This rock on the floor of the quarry, some 100 yards from the main (Bigrigg) fault, is pinkish-grey and calcareous—effervescing freely with cold dilute hydrochloric acid. It yields on pounding a fair amount of finely-divided, red, ochreous material. A few large grains of quartz

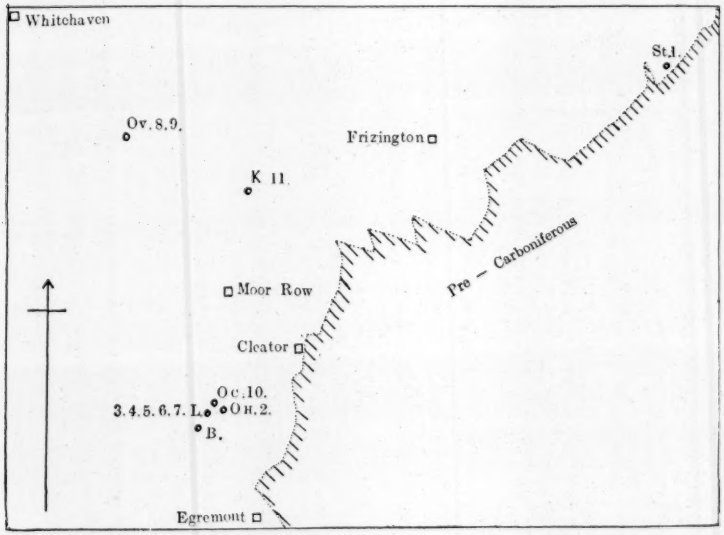

Fig. 1.—Locality map. Localities: St. = Stockhow; Ov. = Overend; K. = Keekle; Oc. = Orepit cutting; Oh. = Orebank House; L. = Langhorn; B. = Bankend. Scale, ½ inch = 1 mile (approx.).

(0·5 mm. to 1 mm.) occur sporadically, but in the main the rock is of fine-sand-to-silt-grade (0·25 mm. to 0·05 mm.). The shape of the grains varies from angular to rounded. Detrital felspar is represented by microcline and perthite, with inclusions of iron-oxide along the cleavages in some instances. In most microsections tourmaline and mica are also to be seen.

The important authigenous constituents are silica, iron-oxide and calcite, the last mineral predominating. In certain portions

[1] For an account of the Lower Carboniferous succession in the district, reference should be made to the paper by Mr. C. Edmonds on "The Carboniferous Limestone Series of West Cumberland," Geol. Mag., LIX, 1922, 74–83 and 117–31. I am indebted to Mr. Edmonds also for supplying the details from which the sections (Fig. 2) have been constructed.

of the rock these constituents appear to be indiscriminately mixed together, in others they occur individually as interstitial elements, the iron-oxide in particular having the appearance of having been massed into certain areas more than others; but usually the secondary minerals are so arranged that a definite sequence in their order is determinable. Thus, the calcite encloses in poecilitic manner grains of quartz heavily coated with reddish-brown iron-oxide, which themselves may enclose original grains of quartz thinly coated with iron-oxide and may also show a later growth of quartz with crystal outlines, exterior to the thick coating of iron-oxide and directly moulded by the calcite (see Figs. 3 and 4). Patches of iron-oxide are in places enclosed by the calcite. Evidence of the mutual operation of siliceous and ferruginous solutions at a stage prior to the deposition of the calcite is presented by portions of the rock which are essentially quartzitic, but in which the secondary growths of silica contain inclusions of iron-oxide, which are sometimes translucent.

Barytes occurs as an authigenous constituent in places in this rock, and is sometimes abundantly represented in the concentrates of heavy minerals obtained by bromoform separation.

As the fault is approached the rock becomes more highly ferruginous, and at the fault the sandstone varies in colour from dark reddish-brown to purplish-red. The size and character of the allothigenous mineral grains remain the same.

In the more highly ferruginous portions of the rock the iron-oxide is the only mineral separating the grains of quartz. The latter, however, often show evidence that regrowth occurred before and during the introduction of the ferruginous material. This material is usually compact iron-oxide, but in places it may occur as small spherulitic growths isolated and scattered in the silica in the quartzitic portions of the sandstone. Every gradation exists, from the scattered spherules, through loose aggregates of these bodies, to compact iron-oxide (see Fig. 5). Blood-red and orange-red translucent inclusions of iron-oxide in the silica are also of common occurrence in microsections of the rock.

In the less ferruginous purplish-red sandstone from near the fault, the texture is identical with that of the calcareous rock exposed on the floor of the quarry. The calcite, however, appears to have been totally replaced by fluorspar (see Figs. 6 and 7). In microsections the fluorspar is colourless and traversed by intersecting cleavage traces. In some portions of the rock where the fluorspar encloses the other minerals in poecilitic manner the rhombohedral cleavage of the original calcite appears to have survived in the pseudomorph.

Fragments of the fluorspar, separated by means of bromoform from the crushed rock, are usually colourless and pitted, but purple and zoned fragments also occur. The identity of the mineral has been confirmed by optical and chemical tests.

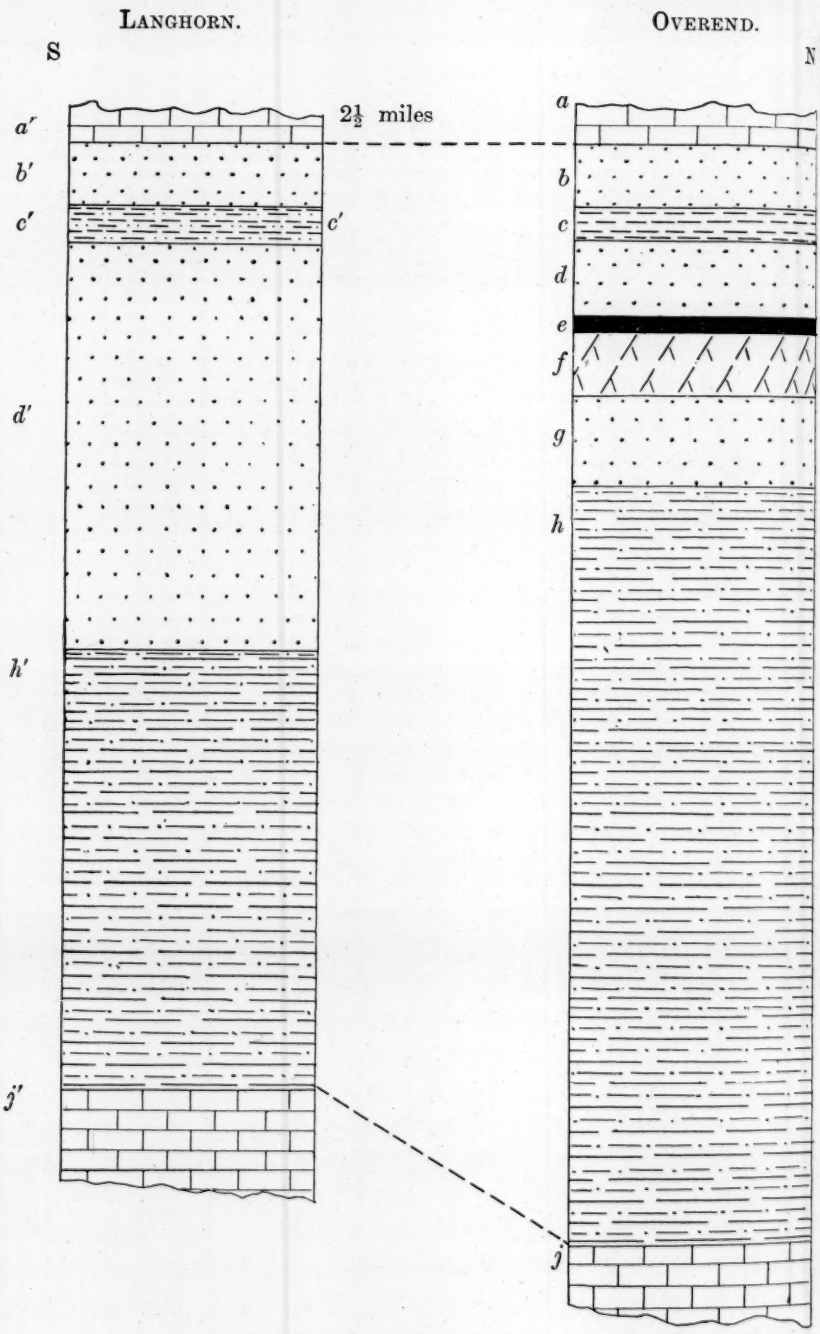

FIG. 2.—Sections at Langhorn and Overend. *a* and *a′* = First Limestone; *b* and *b′*, *d* and *d′* and *g*, = sandstone; *c* = mudstone; *c′* = sandy mudstone; *e* = coal; *f* = fireclay; *h* = sandy shale; *h′* = mottled sandy shale; *j* and *j′* = Second Limestone. Vertical Scale, 1 inch = 3 feet.

Lower Sandstone, Langhorn Quarry.—This rock is a compact, pinkish-grey, quartzitic sandstone. It is in part micaceous and the specimen examined did not effervesce with cold dilute hydrochloric acid. The chief detrital minerals consist of flakes of white mica, a few large clear grains of quartz up to 1·3 mm. in length, scattered among angular and turbid grains of quartz of medium-sand to fine-silt grade, with a fair admixture of grains of felspar.

The predominating authigenous mineral is silica, which occurs either as secondary enlargements of original grains of quartz, bordered faintly by iron-oxide, or as finely granular aggregates, which may contain inclusions of iron-oxide. In a few places iron-oxide occurs as the cementing material and sends out red translucent outgrowths into the associated siliceous material.

Fluorspar occurs in this rock as thin films of faint purple tint infilling joints. In one microsection it has been observed in small amount forming part of the granular mosaic of the rock (see Fig. 8). Fragments of fluorspar from this sandstone exhibit the same characters as do those from the upper sandstone.

The Middle Sandstone, Overend Quarry.—All three sandstones from between the First and Second Limestones at Overend are friable, brown, highly ferruginous and much weathered. The uppermost sandstone (see Fig. 2) is largely composed of brown hydrated iron-oxide ; the lowest sandstone is similar, but contains carbonized plant-fragments.

The middle sandstone consists of angular to subangular grains of quartz varying in grade from medium-sand to medium-silt, with a cement of silica and brown hydrated iron-oxide. The latter has probably resulted from the oxidation and hydration of a ferrous carbonate. Some portions of the rock are quartzitic and in places a small amount of calcite occurs (see Fig. 9). No fluorspar was present in the heavy mineral concentrate, which, however, unlike the concentrates from the sandstones at Langhorn, yielded a fair proportion of garnet.

The Fluorspar and the Iron-Oxide.

Within recent years the controversy concerning the origin of the deposits of haematite in the Lower Carboniferous rocks of Cumberland has been revived. Mr. E. E. L. Dixon, using the association of fluorspar with the ore as part evidence, maintains that the ore was (in part) of magmatic origin ; while Dr. B. Smith reasserts his conviction that the deposits were formed by descending meteoric waters.[1] The present investigation is in keeping with the view expressed by Dr. Smith that, " in the search for light upon the origin of the ore and the source of the mineralising solutions no avenue should be left unexplored." [2] At Langhorn the upper sandstone

[1] *Summary of Progress for* 1927, Geol. Surv. of Great Britain, 23–36.
[2] Loc. cit., 33.

(below the First Limestone) definitely becomes more highly ferruginous as the Bigrigg Fault is approached, and there can be no doubt that the bulk of the iron-oxide in the rock has been deposited from iron-bearing solutions which travelled by way of the fault and which were also in some measure responsible for the deposits of iron-ore which have been worked at several levels on the fault. The present work was undertaken to discover, if possible, the order of deposition of the authigenous minerals in the rock and particularly the relationship which the fluorspar holds to the iron-oxide.

As demonstrated in the descriptions of the rocks, a definite sequence in the mineral deposition has been established. In all the microsections of the upper sandstone, whether they contain

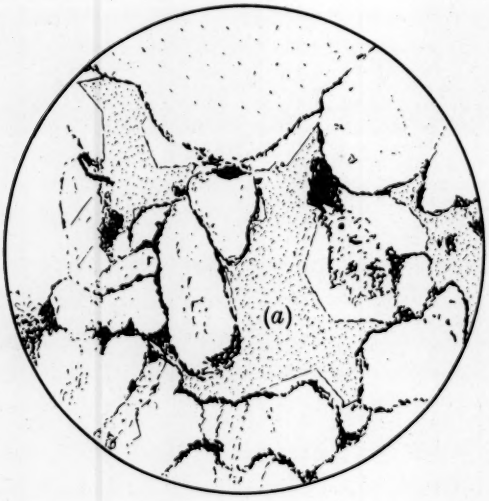

FIG. 3.—Calcareous (upper) sandstone. Floor of quarry, Langhorn, showing calcite (*a*) following quartz with crystal outlines, both minerals being subsequent to the iron-oxide. × 60. Compare with Fig. 7.

fluorspar or not, grains of quartz occur with a light dusting of iron-oxide, exterior to which a regrowth of silica has taken place. Following on this, it would appear that the bulk of the iron-oxide within the rock was introduced and thickly coated the greater number of the grains of quartz, including those previously regrown. At this stage siliceous solutions must also have been in operation as shown by the " quartzitic " nature of portions of the sandstone and by the inclusion within the quartz of opaque grains, translucent plates and spherules of iron-oxide. Subsequently, some grains of quartz, exterior to their heavy coating of iron-oxide, received

an additional deposition of silica which attained definite crystal outlines and acquired the same optical orientation as the original grains.

The last two stages can be traced throughout the sandstone, both near and distant from the fault. They are also directly comparable with those established by Dr. B. Smith for the alteration of the Carboniferous Limestone of the same district to iron-ore [1] and show similarity to the general sequence of deposition in loughs containing haematite and quartz, viz., kidney ore, specular ore with or without quartz, and finally quartz.

In the sandstone on the floor of the quarry at Langhorn, following the last deposition of silica, calcite was introduced,[2] probably from the overlying First Limestone. The entry of the calcite appears in places to have accompanied or followed the corrosion of some of the grains of quartz, which are usually heavily coated with iron-oxide and almost or quite isolated from one another within the calcite. The last growth of crystalline silica is retained on other grains and intervenes between the coating of haematite and the carbonate (see Figs. 3 and 4).

The texture of the sandstone, which is cemented in part by fluorspar at the fault, is so similar to that of the calcareous sandstone on the quarry floor that there can be little doubt that the fluorspar has replaced the calcite. The former mineral appears as a pseudomorph of the latter in every particular. In places, where it forms part of the more "quartzitic" portion of the sandstone, it is unassociated with iron-oxide, but usually it definitely encloses the ferruginous material in a manner exactly resembling that shown by the calcite in the other part of the same bed (Figs. 6 and 7). To some extent, however, the last-formed growths of quartz with crystal boundaries seem, in places, to have been partly removed during the incoming of the fluorspar. Channels, or cracks, also frequently traverse the fluorspar and these may represent contraction-cracks, the change from calcite to the denser fluorspar involving an appreciable reduction in volume.

The replacement of the calcite by fluorspar can have occurred in one of two ways: either by direct interaction between calcite and fluorine compounds of magmatic origin ascending by way of the fault, or by the replacement of the calcite by descending solutions containing fluorspar. In either case the microscopic evidence goes to prove that the solutions in question were not in operation at the same time as the iron-bearing solutions which brought about the maximum deposition of haematite, but that they were introduced into the sandstone at a later date, both

[1] Mem. Geol. Surv. Spec. Rep., *Haematites of West Cumberland*, etc., 2nd ed., 1924, 36.

[2] This is paralleled by the deposition of calcite and dolomite crystals on quartz, or on quartz and specular haematite in many loughs.

siliceous and carbonate solutions having been in operation in the meantime.[1]

The Origin of the Fluorspar.

The fluorspar may have originated in either of the two ways already indicated. Taking a wide view of the occurrence of the mineral in the limestone, sandstone, and ore, there can be no doubt that the fluorspar was introduced initially by the agency of solutions of magmatic origin. Evidence is lacking which would fix, with certainty, the time at which these fluorizing solutions were at work.[2] It is, however, the general opinion that the fluorspar deposits in the Carboniferous rocks of the North of England are of Hercynian age,[3] and grains of detrital fluorspar believed to have been derived from the Carboniferous rocks of the Pennines have been recorded from the basal Permian sands of Yorkshire.[4] Mr. C. Edmonds correlates the First Limestone of West Cumberland with the Great Limestone of Alston, and it is significant that it is at about this horizon that fluorspar deposits largely occur in the respective areas.[5]

If the assumption be made that the deposition of the fluorspar in the Langhorn sandstone took place directly, by the agency of magmatic waters in Hercynian times, then the main deposition of iron-oxide in the sandstone and of the ore deposited by the same iron-bearing solutions must of necessity have occurred at an earlier period, but subsequent to the Hercynian faulting. The field evidence, however, as at present interpreted, conflicts with the origin of the ore in pre-Triassic times. Dr. Bernard Smith has pointed out to me that Mr. Dixon and he are agreed that the period of ore-formation was associated with the post- (or possibly

[1] It is of interest to observe that Mr. Dixon records the following mineral sequence in a lough, "Kidney-ore, specular iron ore, quartz, fluor." *Summary of Progress*, 1928, 31. By this sequence the fact is again emphasized that the fluorspar solutions were at work later than the haematite solutions.

[2] A heavy mineral separation was made from two samples of Brockram supplied by Dr. B. Smith from the east side of the Egremont Road near the Bigrigg Fault (Geol. Surv. Mem., *Haematite*, 2nd ed., 1924, 41–2). No fluorspar was found, but both specimens gave a very heavy crop of barytes, which tended to obscure the presence of other heavy minerals; these, however, included zircon, rutile, tourmaline, magnetite (as rounded grains), and staurolite. One specimen yielded gypsum, together with a small fragment of kidney-ore and of a rugose coral, which had been converted into iron-oxide. The presence of staurolite is of interest as this mineral has not been found in the underlying Carboniferous rocks of the district. Both the gypsum and the barytes appear to be present as authigenous minerals.

[3] A. M. Finlayson, "The Metallogeny of the British Isles," *Quart. Journ. Geol. Soc.*, lxvi, 1910, 281.

[4] A. Gilligan, *Proc. Yorks. Geol. Soc.*, xix, 1918, 289–97, and H. C. Versey, ibid., xx, 1925, 207. A. Holmes and H. F. Harwood believe "the general mineralization followed the intrusion of the Whin Sill and preceded the formation of the Yellow Sands" (Permian), *Min. Mag.*, xxi, 1928, 532.

[5] Mem. Geol. Surv. Spec. Rep., *Lead and Zinc Ores of Northumberland and Alston Moor*, 1923, by Stanley Smith.

late) Triassic faulting. He, further, makes the suggestion that at Langhorn the fluorspar may have ascended the Bigrigg Fault (a Hercynian fault, which had a slight movement in post-Triassic times) in Hercynian times and have been redistributed in post-Triassic times.

The First Limestone at Langhorn carries crystals of fluorspar (averaging 3 mm. in diameter) as joint filling.[1] This limestone was jointed in Carboniferous times. Hence, Dr. Smith suggests, if the fluorspar ascended the fault during the Hercynian period, some may have been deposited in the limestone fairly abundantly near the fault and have worked its way downwards at a later (post-Triassic) date, the circumstance that it was the last mineral to be deposited, being due, possibly to the difficulty of its solution. Instances can be cited where fluorspar deposits in other parts of the world are believed to have been formed, in part, by the agency of meteoric waters.[2] Downward percolation of the fluorspar solutions from the overlying limestone may therefore have resulted in the replacement of the calcite in the calcareous sandstone at Langhorn.

The Heavy Minerals in the Lower Carboniferous Sandstones.

Although the grain-size, texture, and general composition of the Carboniferous sandstones examined vary somewhat, yet the allothigenous mineral species are much alike in each assemblage. The chief detrital minerals represented are quartz, felspar (chiefly perthite and microcline with some plagioclase), mica, zircon, rutile, tourmaline, garnet, epidote and iron-oxides. The authigenous constituents present include iron-oxides, silica, calcite (and other carbonates), barytes, fluorspar, and gypsum.

Garnet.—This mineral is well represented in the sandstones at Overend. Grains from the middle sandstone (see Figs. 2, 10, and 11) are pink or colourless, irregular, and occasionally etched. The rhombic-dodecahedral cleavage is well shown. The grains vary from 0·65 mm. to 0·07 mm. in maximum diameter. Grains of this mineral (0·4 mm. to 0·12 mm.) often presenting very irregular outlines occur in the first sandstone above the First Limestone at Overend. In the remainder of the sandstones examined one typical grain (0·16 mm.) was detected in the sandstone between

[1] This information was supplied by Mr. C. Edmonds, who informs me that "fluorspar occurs at Langhorn in the First Limestone, the sandstone below, the Second Limestone and at the top of the Orebank Sandstone". In the last instance the sandstone sometimes contains hollow spheres of haematite within which Mr. Edmonds has found cubes of fluorspar. These spheres are of concretionary origin and many of them contain no fluorspar. Other occurrences of fluorspar in West Cumberland are mentioned by Mr. Dixon (op. cit., 1928, 31).

[2] The occurrence of stalagmites and stalactites composed of fluorspar and barytes in a cave on the Bailey property, Madoc, Ontario, is recorded by M. E. Wilson, *Geol. Surv. Canada*, Econ. Series, No. 6, 15 and 67.

the Fifth and Sixth Limestones at Stockhow and another (0·05 mm.) in the interesting gypseous second sandstone above the First Limestone of Orepit cutting.

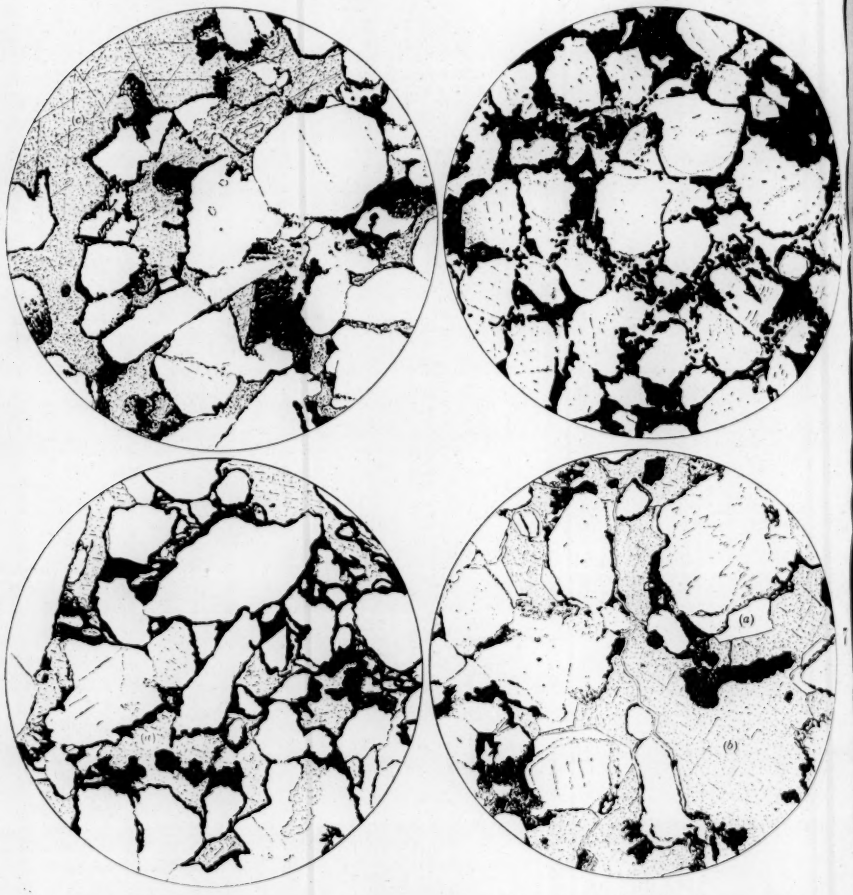

Fig. 4.—Calcareous (upper) sandstone, below First Limestone, Langhorn (100 yards from fault). × 26. Corroded grains of quartz, thickly coated with iron-oxide and set in calcite (*c*). Compare with Fig. 6.

Fig. 5.—Ferruginous (upper) sandstone, Langhorn (at the fault). × 26. Showing the result of the mutual activity of ferruginous and siliceous solutions.

Fig. 6.—Sandstone with fluorspar cement (*a*). Upper sandstone below First Limestone, Langhorn (at the fault). × 26. Compare with calcareous sandstone, Fig. 4.

Fig. 7.—Sandstone with fluospar cement. Upper sandstone below First Limestone, Langhorn (at the fault). × 26. Quartz, showing more than one stage of regrowth, the last deposit with crystal outlines (*a*) being subsequent to the thick coating of iron-oxide, but preceeding the fluorspar (*b*). Compare Figs. 3 and 4.

Zircon occurs in all the heavy concentrates and includes good prismatic forms (0·4 mm. to 0·05 mm.), stumpy crystals (0·25 mm. to 0·05 mm.) with flat terminations at one or both ends, rounded grains (0·25 mm. to 0·05 mm.), and broken prisms (0·3 mm. to 0·05 mm.). The majority of the grains are colourless and many have inclusions, while some are zoned. Purple zircons of rounded and prismatic form (0·17 mm. to 0·1 mm.) occur throughout and yellow prismatic crystals are also present.

In the upper sandstone below the First Limestone at Langhorn crystals of zircon (0·12 mm.) with double terminations occur (see Fig. 11). These are of interest because similar forms occur in the Peel Sandstone of the Isle of Man and in the Whitehaven sandstone at Keekle. They have also been recorded by Dr. Rastall and Mr. Wilcockson from the granitic rocks of the Lake District.[1]

In the Langhorn sandstone and also in the sandstone from Stockhow, crystals of zircon in which one half is more elongated than the other are present (see Fig. 11). Broken crystals, which have been subsequently subjected to corrosion and crystals showing an incipient pyramidal cleavage, also occur.

Rutile is present in all the sandstones as red and yellow fragments and prismatic crystals (0·53 mm. to 0·08 mm.). Rounded forms (0·2 mm. to 0·08 mm.) are sometimes present. Crystals of hammer-head shape are of frequent occurrence in the upper sandstone of Langhorn, together with striated forms, several of which are twinned. Large geniculate twins (0·5 mm.) some with striated faces, are common in the sandstone at Overend at the same horizon (see Fig. 11).

Tourmaline occurs in all the sandstones. It is represented by smoky prismatic crystals and irregular grains and by smoky to blue and green rounded grains. Some irregular fragments (0·5 mm.) and prisms (0·25 to 0·12 mm.) contain abundant inclusions. In the Upper Carboniferous Whitehaven Sandstone of Keekle, tourmaline, as smoky, longitudinally striated, prismatic crystals (0·35 mm. to 0·15 mm.) and rounded grains of pink to brown colour, proved to be much more abundant than in the Lower Carboniferous sandstones of the same district. Pitted grains of tourmaline occur in the upper sandstone of Langhorn quarry.

Epidote.—A few grains of this mineral, of greenish colour and rounded prismatic form, are present in the sandstones from Langhorn (0·26 mm.) and Overend (0·16 mm. to 0·12 mm.).

Muscovite occurs as flakes in all the sandstones, and flakes of a green mica have been observed in the sandstone above the First Limestone at Overend and in the sandstone between the Fifth and Sixth Limestones at Stockhow.

Ilmenite and Magnetite are not abundant, but occur as irregular and rounded grains (0·2 mm. to 0·12 mm.), the former, in part, represented by leucoxene.

[1] *Quart. Journ. Geol. Soc.*, lxxi, 1917, 612.

Haematite is the common authigenous mineral in most of the sandstones and occurs in a variety of forms, but mainly as fragments and rounded aggregates.

Goethite is closely associated with haematite throughout. In the three sandstones below the First Limestone at Overend, brown limonitic iron-oxide is the dominant hydrated form.

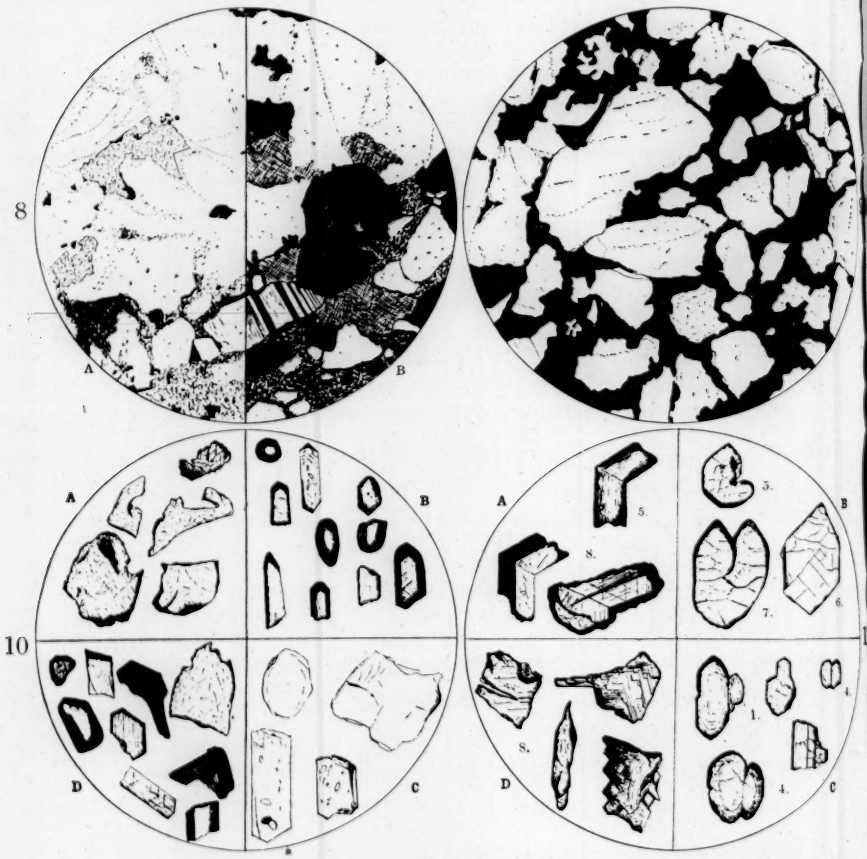

Fig. 8.—"Lower" sandstone from below the First Limestone, Langhorn. A, in ordinary light, B between crossed nicols (somewhat diagrammatic). Note the "fluospar" (*a*) in the quartzitic portion of (A).

Fig. 9.—Ferruginous (middle) sandstone, Overend. × 26. Some grains of quartz are corroded, others regrown.

Fig. 10.—Mineral grains from the (middle) sandstone below the First Limestone, Overend. × 26. A, garnet; B, zircon; C, tourmaline; D, tutile.

Fig. 11.—Heavy Minerals from the Lower Carboniferous Sandstones of Cumberland. A, rutile (geniculate twins), B and C, zircon (double forms, etc.), D, garnet. (The numbers correspond to those in the table on page 555.)

Barytes occurs as an authigenous constituent in fair amount in the Orebank Sandstone and in one specimen of the upper sandstone from the floor of Langhorn quarry.

Calcite and *Fluorspar* occur as authigenous minerals and have been described in the first part of this paper.

Gypsum is found in the second sandstone above the First Limestone of Orepit cutting. As seen in thin section the rock consists of reddish-brown layers of iron-oxide alternating with layers of gypsum with some carbonate. Sharply angular grains of quartz are scattered throughout the rock. On boiling the sandstone with hydrochloric acid, concentrating and cooling the resulting solution, a large precipitate of acicular crystals of selenite was obtained. This was washed to free it from ferric-hydroxide and the crystals identified by their optical properties.

The Distribution of the Heavy Minerals.

The tabulation of heavy mineral occurrences adopted here is that which indicates the percentage composition of the heavy mineral assemblages in the rocks considered, calculated as suggested by Dr. Woolridge and Dr. Fleet.[1] In the table the dominant allothigenous minerals alone are included and percentages stated to the first decimal place. The minerals enumerated are zircon, tourmaline, rutile, garnet, ilmenite and magnetite. (No. 8 gave 0·5 per cent of epidote and No. 13, 3 per cent of apatite.)

	Z.	T.	R.	G.	I. & M.
1	86·2	2·9	6·0	0·1	4·8
2	81·2	3·8	9·9	—	5·1
3	75·4	1·7	17·2	—	5·7
4	74·9	2·8	15·3	—	7·0
5	83·1	1·8	8·5	—	6·6
6	83·1	1·0	9·5	—	6·4
7	73·8	1·0	11·2	—	14·0
8	65·5	0·6	9·3	22·2	1·9
9	68·8	4·1	9·2	11·0	6·9
10	71·1	4·4	4·4	0·1	20·0
11	32·5	35·1	10·1	0·1	22·2
12	76·1	8·3	3·6	—	12·0
13	35·4	31·4	4·7	4·3	21·2

1. Sandstone between Fifth and Sixth Limestones, Stockhow. Fine-grained micaceous rock, white or mottled with red streaks and blotches.

2. Orebank Sandstone, Orebank House; fairly compact pinkish-grey sandstone of medium grain. The top bed of the Orebank

[1] S. W. Woolridge, *Proc. Geol. Assoc.*, 1926, 98, and W. F. Fleet, GEOL. MAG., 1926, 505–7.

Sandstone at this locality is a fine-grained quartzitic sandstone, or "crowstone", veined with brownish-red iron ore. The rock also encloses spheres of red to black iron-oxide within which is usually rock material of quartzitic texture similar to that of the normal rock, with or without an iron-oxide cement. Within hollow spheres of haematite in this rock Mr. Edmonds has found cubes of fluorspar. In the specimen which I have examined no fluorspar was seen and microsections through the spheres of haematite proved them to be of concretionary origin.

3–8. Sandstones between the First and Second Limestones, viz., 3, lower sandstone at the fault, Langhorn; 4 and 5, upper sandstone at the fault, Langhorn; 6 and 7, upper sandstone on the floor of the quarry, Langhorn; and 8, middle sandstone at Overend.

9. First sandstone above First Limestone, Overend. Coarse (conglomeratic) felspathic and micaceous grit, much weathered.

10. Second sandstone above First Limestone, Orepit cutting. Thin banded gypseous and ferruginous sandstone with mica.

11. Whitehaven Sandstone, Keekle. Medium-grained, pinkish-grey, felspathic and micaceous sandstone.

12. Carboniferous Basement Conglomerate, Langness, Isle of Man.

13. Carboniferous Basement Sandstone, Eglwyseg, Llangollen, N. Wales.

The percentage of zircon throughout the sandstones of Lower Carboniferous age in West Cumberland is high and uniform compared with the precentages of the other detrital heavy minerals present. In this respect similarity is shown to the Carboniferous Conglomerate of Langness in the Isle of Man and to the Carboniferous sandstones of North-Eastern Ireland.[1] In both the West Cumbrian and Irish sandstones there are also low percentages of tourmaline, contrasting with the higher percentages from the Carboniferous Basement Sandstone of Llangollen and from the Upper Carboniferous Whitehaven Sandstone of Keekle. Rutile is particularly abundant in some of the Cumbrian sandstones and is common in all. It is also common in the Carboniferous sandstones of North-Eastern Ireland.

While garnet is well represented in the Overend sandstones, it is absent or rare in all the other sandstones and is absent in the Langhorn sandstones which are at the same horizon as the Overend sandstones. (This scarcity of garnet appears to continue to higher horizons, two characteristic grains only being found in a specimen of the St. Bees Sandstone from Bankend Quarry, while Dr. Tyrrell records no garnet from the New Red Rocks at Seascale.[2]) In

[1] Miss D. L. Reynolds, GEOL. MAG., 1928, 465.
[2] J. W. Gregory, GEOL. MAG., 1915.

the Carboniferous sandstones of North-East Ireland garnets may be rare or frequent. T. O. Bosworth [1] and, more recently, B. H. Barrett [2] have shown that the distribution of garnet in the Lower Carboniferous sediments of the Midland Valley of Scotland is very irregular. The garnets from these Scottish rocks resemble closely those in the sandstones at Overend.

The absence or scarcity of garnet at the several horizons as the older rocks of the Lake District are approached, would indicate an extra-Cumbrian source of origin for the garnetiferous sandstones at Overend. On the other hand, the presence of crystals of zircon with double terminations and other characters similar to those recorded by Dr. Rastall and Mr. Wilcockson from some of the granitic intrusions in the Lake District, points to the possibility of the latter having furnished part of the Lower Carboniferous sediments of West Cumberland. That the Manx-Cumbrian ridge of pre-Carboniferous rocks, which was undergoing submergence, was not, however, the main source of supply, is demonstrated by the thinning of the rocks of detrital origin interbedded with the limestones, as the district here considered is approached from the north and north-east.[3] It is therefore probable that the garnetiferous Overend sandstones were derived from a north-eastern source and deposited within an earlier extension of the area of deposition and distribution of the highly garnetiferous "millstone grit", which, lithologically, the sandstone above the First Limestone at Overend much resembles.

In conclusion, I wish to express my indebtedness to Mr. Charles Edmonds, who supplied me with the specimens of the sandstones described and gave me information with regard to their occurrence in the field. I am also most grateful to Dr. Bernard Smith for his helpful suggestions and criticism, and for providing me with specimens of brockram.

[1] T. O. Bosworth, *Proc. Geol. Assoc.*, 1913, 57, and pls. 10 and 11.
[2] B. H. Barrett, GEOL. MAG., 1929, 480.
[3] J. G. Goodchild, *Trans. Cumb. & Westmoreland Assoc.*, No. 16, 1890–1, 134, and Ch. Edmonds, GEOL. MAG., 1922, 77 and 78.

REVIEWS.

CORAL REEFS AND ATOLLS. By J. STANLEY GARDINER. pp. viii + 181, with xv plates and 33 figures in text. London: Macmillan, 1931. 10*s.* 6*d.* net.

THIS volume is based on a course of lectures delivered by the author at the Lowell Institute, Boston, in February, 1930.

Whilst not written in a rigidly scientific manner, the book contains a wealth of interesting matter. The author is a well-known authority on coral islands and reefs, and he has had far more field experience than any other writer on this subject in Great Britain.

Not very long ago W. M. Davis published his monumental work, *The Coral Reef Problem.* Professor Gardiner's book is by no means so extensive as this, but it is particularly interesting in that it presents a totally different point of view—that of a biologist as opposed to a physiographer. Coral reefs present numerous problems, and close collaboration of workers in many branches of science is necessary before anything like a final report, or comprehensive theory, can be presented. Professor Gardiner naturally gives precedence to the biological aspects of the problem, and the geographer and geologist will welcome the book for this reason. He uses simple language and the non-expert reader will be able to gain much valuable information about the natural history of corals and of the many other animal and plant organisms which go to make up that complex called a coral reef.

Another point of interest is the description given of island formations. Too often an atoll, or allied feature, is described in some such words as "a ring of coral carrying sandbanks and supporting vegetation". The author goes much more fully into the history and development of these structures, and the physiographer will do well to read these sections with care, for such islands afford many interesting problems in the evolution of sand spits, beach sandstones, coral limestones, etc. Similarly, the lecture on atolls and their lagoons is worth careful study.

The final chapter on the Foundations of Atolls is, perhaps, rather disappointing. Rightly, the author points out that theorists are apt to run riot when dealing with the attractive hypotheses of subsidence, planation, or upward building of banks to bring them into depths suitable for coral growth to begin. Up to a point we can agree with such a statement as: "If we regard the question of the formation of the foundations of coral reefs honestly, we are forced to admit that all theories and considerations are mere camouflage for our lack of knowledge." But this, perhaps, goes rather far. Davis, in his careful analysis, has certainly shown that reefs must be studied in close connection with the tectonic and physiographical problems of the adjacent land. Hence, whilst frankly admitting that

any generalized theory of atolls rests, at best, on circumstantial evidence, it is a different matter for a great mass of reefs such as border New Caledonia and Queensland. That we know the origin and foundation of such reefs is not assumed, but surely sufficient work has been done to make us tolerably certain that we are working on very reasonable grounds? "De mortuis nil nisi bonum"; it is, however, difficult to avoid feeling that Professor Gardiner has somewhat overrated the work of Agassiz. Agassiz saw more reefs than any writer on coral structures, but it must be admitted that in some cases his *physiographic* reasoning was rather lax.

However, to put forward criticisms on the last chapter of this volume is merely to start again the never-ceasing debate on the origin of coral reefs. The author has refrained from doing this and has stated concisely some of his own views on the matter, and the reader must use his own discretion before accepting them.

The book is a very welcome addition to the literature of coral reefs, and the more so because it draws attention to, and describes simply but effectively many features of reefs which are not often obtainable except in exhaustive treatises on particular areas. The physiographer and the general reader will do well to read it and consider its contents in relation to theoretical generalizations.

J. A. Steers.

The Figure of the Earth. National Research Council, Bull. 78. pp. vi + 286. Washington, 1931.

In 1926 a number of sub-committees were appointed by the National Research Council of the National Academy of Sciences to prepare a series of reports on *The Physics of the Earth*, each intended "to give to the reader, presumably a scientist, but not a specialist in the subject, an idea of its present status together with a forward-looking summary of its outstanding problems". This ambitious project is now rapidly coming to fruition. Bulletins on *Volcanology*, *Meteorology*, *The Figure of the Earth*, and *The Age of the Earth* have been issued this year, and others are promised at an early date on such subjects as *Seismology*, *Terrestrial Magnetism*, and *The Internal Constitution of the Earth*. These will serve much the same purpose as the geophysics volumes of the monumental *Handbuch der Experimentalen Physik*, but while the latter are more technical and comprehensive, the former are likely to make a wider appeal to English-speaking geologists, and especially to those who are not particularly mathematically-minded.

The scope of the volume under review is best indicated by the list of contents: *Introduction* (G. T. Rude); *Tidal Theory* (A. T. Doodson); *Tidal Computations and Predictions* (P. Schureman); *Mean Sea Level* (H. A. Marmer); *Earth Tides* (W. D. Lambert); *Tidal Friction* (W. D. Lambert); *Isostasy*

(W. Bowie); *The Influence of Isostasy on Geological Thought* (H. F. Reid); *The Shape and Size of the Earth* (W. D. Lambert); *Determination of "g" by means of the Free Swinging Pendulum* (C. H. Swick); *Gravity Measurements with the Eötvös Torsion Balance* (D. C. Barton); *Geodetic Instruments* (D. L. Parkhurst); *On Some of the Greater Problems of Physical Geology* (C. L. Dutton); *The Determination of Elevations* (H. G. Avers); *The Determination of Geographic Position* (C. V. Hodgson); and *The Variation of Latitude* (W. D. Lambert, F. Schlesinger, and E. W. Brown).

It will be noticed that one of the chapters is a reprint of Dutton's paper of 1889, in which the word "isostasy" was first used. It was a happy idea to make this geological classic so readily accessible. The other contributions on isostasy are less complete and rigorous than might have been expected. Reid discusses the isostatic significance of the fact that many mountain ranges have been elevated long after the folding, but he does not draw attention to the more puzzling fact that others have subsided. Clearly the history of folded belts is controlled by other factors superimposed upon the prevailing tendency to equilibrium implied by isostasy. The chapters by Lambert give a particularly lucid treatment of the topics they present. Dealing with tidal friction, Lambert mentions the resonance hypothesis of the separation of the moon from the earth, but he cautiously remarks that this speculation is not universally accepted. As Jeffreys has recently given good reasons for abandoning it, we are left with no satisfactory hypothesis for either the origin of the moon or the concentration of the sial-layer of the earth into continental blocks. The origin of the continents and of the Pacific Basin is thus returned to the category of unsolved problems.

Intending purchasers of the Bulletin should notice that the four now issued are obtainable at a reduced price ($10.00) if all are ordered together.

A. H.

CORRIGENDUM.

In the paper by Dr. G. D. Osborne upon "Contact Metamorphism and Related Phenomena in the neighbourhood of Marulan, N.S.W.", which appeared in the July number of the GEOLOGICAL MAGAZINE, the sentence on page 305, line 23, beginning "It must be remembered . . ." should have read:—

> It must be remembered in dealing with the present, or any analogous case, that lowering of temperature in the magma follows its intrusion, with resulting crystallization, which is accompanied by endothermic reactions in the aureole.

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